DEVELOPMENT OF ADVANCED HIGH-PERFORMANCE BATTERIES FOR 12V START STOP VEHICLE APPLICATIONS

Principal Investigator: Jeffrey Kim

Maxwell Technologies, Inc.

June 7, 2016

Project ID # ES251

Overview

Timeline

- Start: October 2014
- Finish: June 2016 *
- On schedule, 90% complete ‡

Budget

- Project Funding
  - USABC: $1.31M
  - Maxwell: $1.37M
  - **Total: $2.68M**

Barriers Addressed ┼

- The enablement of a low cost ultracapacitor pouch cell configuration
  - Gas management
  - Packaging development
- Development of an advanced energy management system
  - Efficient distribution of power and energy within the module

<u>Maxwell System Targets</u>

- System Weight = 10 kg
- System Volume= 7 L
- System Selling Price= $180 (@250K units/year)

* 2 month extension ‡ as of April 2016 ┼ towards *DOE VT Program Multi-Year Program Plan*

Maxwell TECHNOLOGIES Enabling Energy's Future™

Definitions

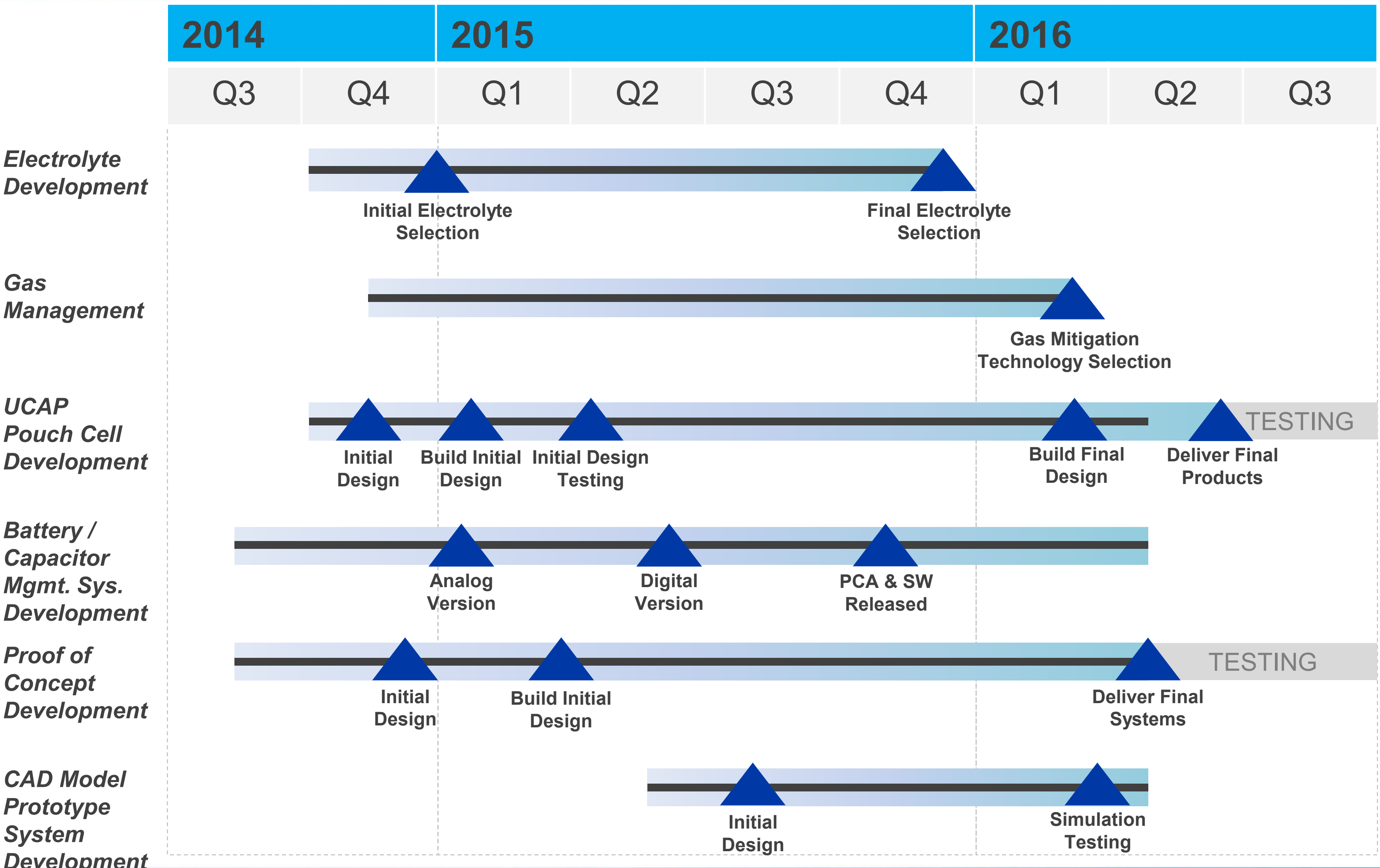
Proof-of-Concept System	• Testable module used for in-house feasibility study and for delivery to the national labs for performance evaluation • OTS $LiFePO_4$ battery cells • Maxwell UCAP cylindrical cells
Prototype System	• CAD model only • LiFePO4 pouch cells • Maxwell UCAP pouch cells

Objectives and Relevance

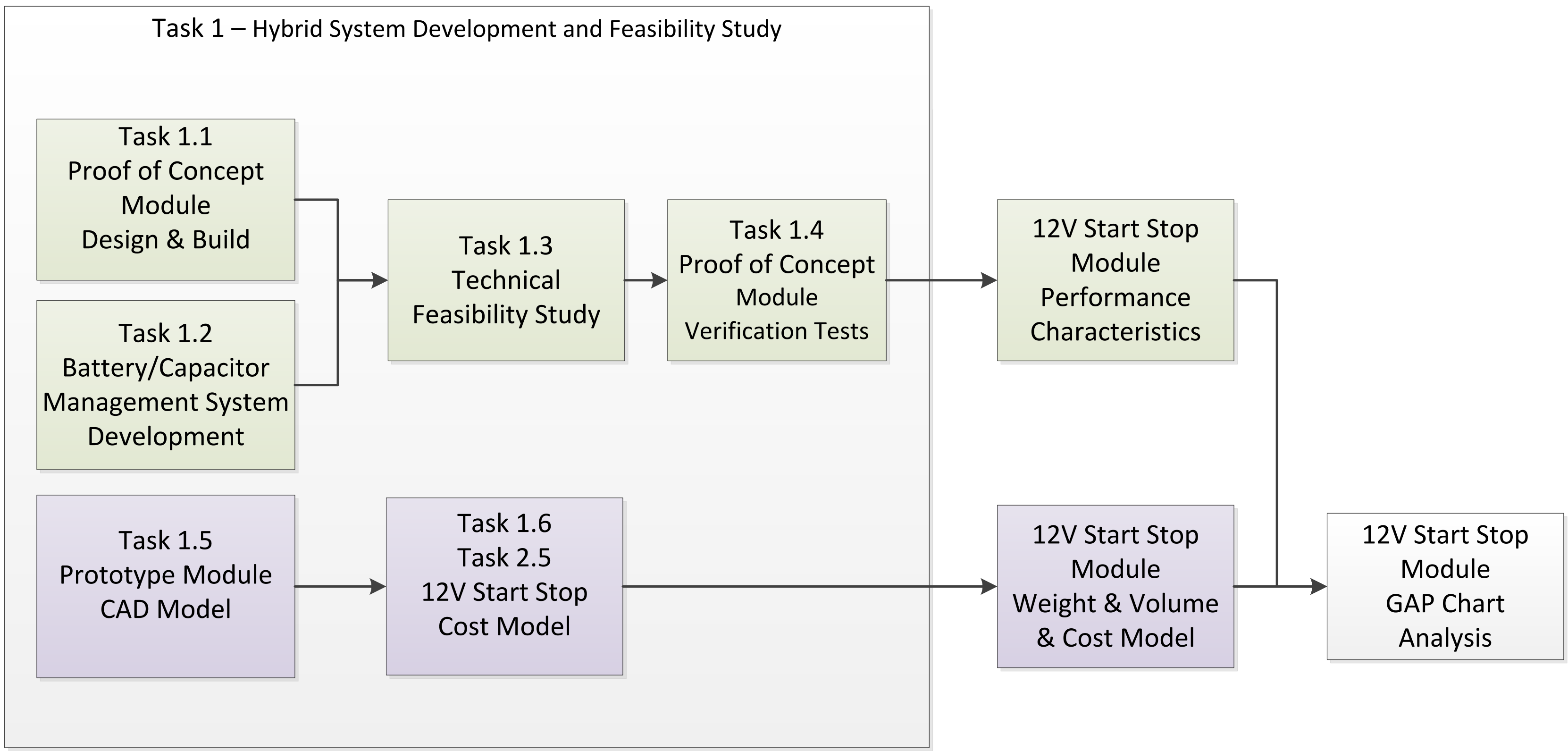
Program Objective: To demonstrate the technological and economic feasibility of a hybrid (UCAP/LIB) energy storage system in an automotive Start Stop application.

- The study of the electrical, life cycle and control/communication performance of the hybrid system
- Development of a low cost UCAP pouch cell
  - Optimized weight, cost and performance
- A comprehensive CAD System Design
  - Validate the system weight, volume, and cost
  - Determine critical thermal and vibration characteristics

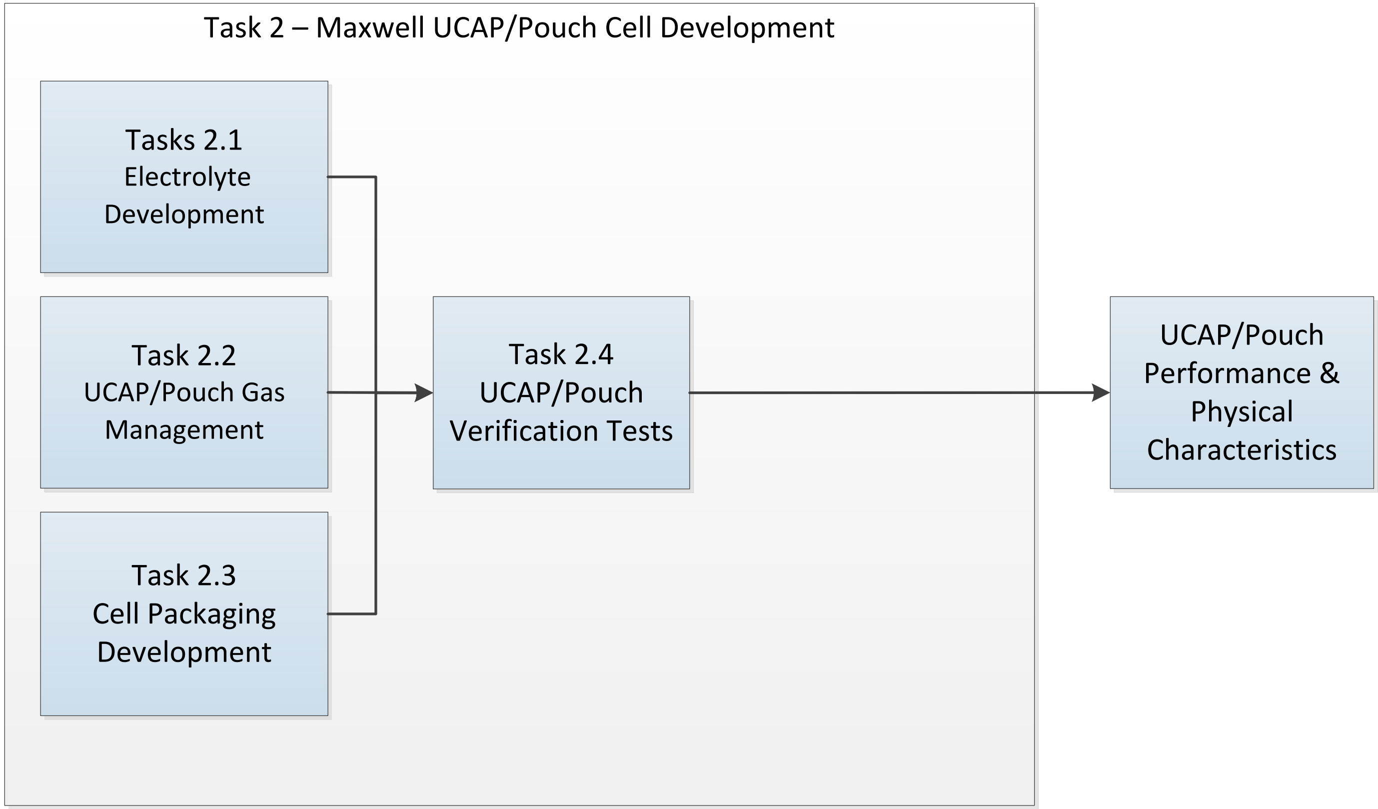
Project Milestones and Gates



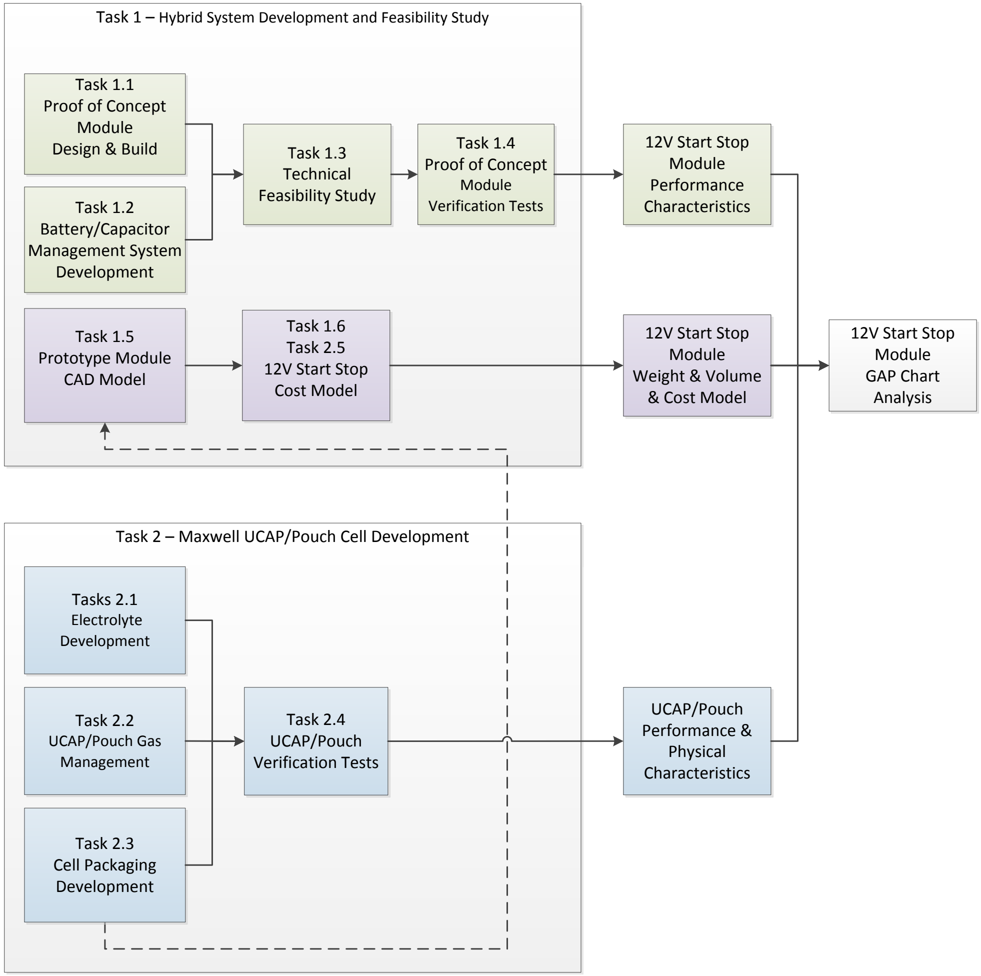
Strategy – Task 1 Hybrid System Development & Study



Strategy – Task 2 UCAP Pouch Cell Development



Program Strategy



Technical Approach – Cell Development

Objective: Develop a robust UCAP pouch cell string configuration for the system.

- Enable a UCAP pouch cell configuration:
  - Electrolyte formulation modification
  - Gas suppression additives
  - Optimization of cell packaging design
- Build, pre-screen and ship UCAP pouch cells to the national labs for confirmation of performance and abuse conformance.
- Develop a UCAP pouch cell cost model based on prototype manufacturing results identifying a pathway to meeting program cost targets.

Maxwell TECHNOLOGIES Enabling Energy's Future™

Technical Approach – System Development

Objective: Develop and demonstrate the technical and economic feasibility of the proposed Maxwell 12V Start Stop System.

- Design and construct Proof of Concept systems.
- Develop a Battery/Capacitor Management System (BCMS).
- Optimize and demonstrate the feasibility of the intended hybrid system using a combination of criteria.
  - USABC Gap Chart
  - FreedomCar test parameters
- Develop a CAD model of the 12V Start Stop Module using anticipated UCAP pouch cell specifications.
- Develop a system cost model.

FY 2015 Technical Accomplishments – Cell Electrolyte Development

Identify an electrolyte formulation that minimizes high temperature gas generation while having no negative impact on other key cell operating characteristics.

- Evaluation of several formulations of acetonitrile and carbonate based electrolytes completed.
  - Formulation selection finalized with improvements demonstrated to control gas generation.
- Evaluation of several ionic liquids with improved thermal and electrochemical stability completed.
  - No effective and practical solution identified, effort concluded.
- Evaluation of several gas suppression additives completed.
  - Additive selection finalized with improvements demonstrated to reduce gas generation.

FY 2015 Technical Accomplishments – Cell Gas Management

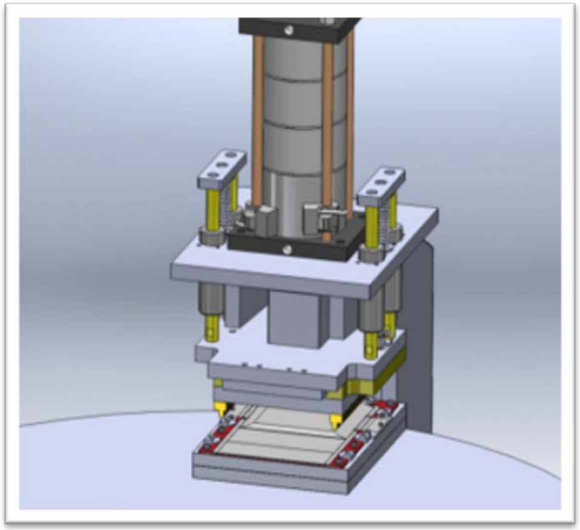
Explore the concept of a gas getter that can reduce high temperature gas pressure while having no negative performance impact on other key cell characteristics.

- Study of the gas generating mechanisms completed.
- Evaluation of several separators to minimize gas generation completed.
  - Separator selection finalized.
- Evaluation of gas management strategies to backup fundamental gas generation mitigation strategies completed.
  - Gas Release Valve evaluations concluded, though technical challenges led to an abandoned effort.
  - Gas Getter evaluations concluded, though no practical and cost effective solution was identified.

FY 2015 Technical Accomplishments – Cell Packaging Development

Objective: Improve the internal gas pressure containment capability of the cell.

- The UCAP pouch cell design has been completed.
- Related fixture and tooling has been completed.
- Cell fabrication process development completed and optimized for ESR and minimal gas generation.
- Pouch cells built, performance demonstrated to meet targets.



FY 2015 Technical Accomplishments – System Development

Proof of Concept Module Design and Build

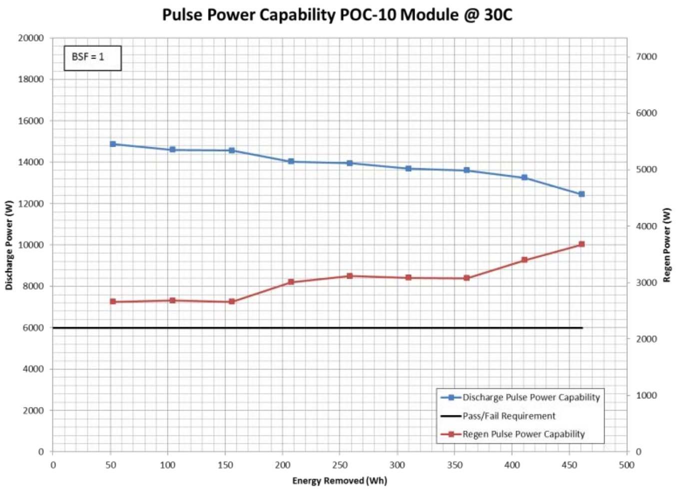
- Proof of Concept development completed.

Battery/Capacitor Management System Development

- Analog version of the system board design for the initial Proof of Concept system completed.
- Digital version of the system board design completed with LIN communications enabled for polling diagnostics.

Technical Feasibility Study

- Proof of Concept Module used to gauge design performance vs. gap chart targets.
- HPPC data performed w/BSF = 1
- Meets available energy and cold crank requirements at a fraction of the cost of a battery-only solution.



Cost Model

Objective: Develop a cost model for the proposed Maxwell 12V Start Stop System assuming annual production volume at 250k.

- A comprehensive cost model is being finalized.
- Work focused on both traditional cost down strategies and innovative new cell manufacturing techniques.

	Est. System Price (250K units/year)
Beginning of Program	$230
End of Program Target	$180

Responses to Previous Year Reviewer's Comments

Question 2: Technical Accomplishments and Progress toward overall project and DOE goals – the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

- The reviewer reported that a considerable amount of work was done on evaluating electrolytes with acceptable gas formation with two candidates identified for future work. It would be advisable to continue screening for better electrolytes and to evaluate separators and other components that might lower the gas formation at high temperatures. The reviewer added that depending on a gas getter of some type to mitigate, the gas level may not be an approach that provides consistent quality.

Response

- Additional work was done in further evaluating several additional electrolyte formulations and separators resulting in a final selection with an ideal balance of minimized gas generation and performance characteristics needed.

- Progress has been made in better understanding the mechanisms of gas formation. Initially, a gas getter strategy was adopted to counteract the gas generation within the cell, though the effort was abandoned in favor of a more effective and economical gas suppression strategy instead. Several additives have been evaluated with a final selection chosen in demonstrating a significant reduction in gas.

Collaborators

Argonne National Laboratory
FFRDC, cell and system performance characterization

National Renewable Energy Laboratory
FFRDC, thermal modeling and testing

Sandia National Laboratories
FFRDC, abuse tolerance characterization

Argonne NATIONAL LABORATORY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Sandia National Laboratories

Gap Chart Analysis

End of Life Characteristics	Units	USABC - Not under hood	SOW proposal	Maxwell Tests *
Discharge Pulse, 1s	kW	6.0	6.5	14.0
Max current, 0.5s	A	900	1200	1000
Cold cranking power at -30°C (three 4.5s pulses, 10s rests between pulses at lower SOC)	kW	6kW for 0.5s followed by 4kW for 4s	3 Cranks	2.8 Cranks
Min voltage under cold crank	Vdc	8.0	8.2	8.0
Available energy (750W accessory load power)	Wh	360	360	450
Peak recharge rate, 10s	kW	2.2	2.6	2.6
Sustained recharge rate	W	750	750	750
Cycle life, every 10% life RPT with cold crank at min SOC	engine starts/miles	450k/150k	450k	23k
Calendar life at 30°, 45°C if under hood	Years	15 at 30°C	15 at 30°C	-
Minimum round trip energy efficiency	%	95	95	97
Maximum allowable self-discharge rate	Wh/day	2.0	1.7 at 30°C	1.3 at 30°C
Peak operating voltage, 10s	Vdc	15	15	14.4
Sustained Operating Voltage - Max	Vdc	14.6	14.6	14.0
Minimum operating voltage under Autostart	Vdc	10.5	10.5	11.8
Operating temperature range (available energy to allow 6 kW (1s) pulse)	°C	-30 to +52	-30 to +52	-30 to +52
+30 to +52	Wh	360	360	460
0°C	Wh	180	180	440
-10°C	Wh	108	108	420
-20°C	Wh	54	54	400
-30°C	Wh	36	36	220
Survival temperature range (24 hours)	°C	-46 to +66	-46 to +66	-
Maximum system weight	kg	10.0	9.6	7.2
Maximum system volume	L	7.0	7.0	6.8
Maximum system selling price (@250k units/year)	$	$180	$230 with path to $199	-

* Performance as of April 2016 (Proven Status based on in-house tests)

Remaining Challenges and Barriers / Proposed Future Work FY 2016

Remaining Challenges and Barriers

- Validations to quantify research efforts.
  - Final UCAP pouch cell configuration
  - Performance characteristics of an advanced energy management system

Proposed Future Work FY 2016

- Testing at the national labs to characterize cell and system performance and to validate thermal and abuse characteristics.

Summary

There is a very strong technical and economic case developing in the energy storage industry for the hybrid combination of ultracapacitors (UCAP) and batteries in a variety of applications.

- The program has advanced on both tasks – low cost UCAP pouch cell development and full 12V Start Stop System design.
- The UCAP pouch cell development has demonstrated a solution in overcoming the electrochemical challenges faced in this form factor.
- The 12V Start Stop System development resulted in a practical design meeting all technical requirements in the intended application.